5.0 HYDROLOGIC ANALYSIS

5.1 INTRODUCTION

Hydrologic analysis of the Cool Creek watershed was performed to assist in problem identification and develop solutions and recommendations. The hydrologic computer model HEC-HMS (U. S. Army Corps of Engineers, Hydrologic Engineering Center – Hydrologic Modeling System, Version 2.2.1) was used to perform the peak stormwater runoff analysis. HEC-HMS is a physically based storm event simulation model capable of simulating runoff from various land uses and soil types, combining subbasin hydrographs, and routing flow through storage and conveyance facilities. Flows from the HEC-HMS model were used as inputs to the hydraulic analyses of the stream system (Chapter 6).

A second hydrologic model, XP-SWMM, was used to analyze potential off-line regional detention facilities. XP-SWMM is a dynamic (unsteady) flow model that performs both hydrologic and hydraulic analyses and can more accurately account for unsteady flow conditions associated with off-line detention facilities. The following sections describe the model development, evaluation results, and conclusions.

5.2 HEC-HMS MODEL DEVELOPMENT

HEC-HMS model development requires delineation of subbasins within the watershed, determining land use and runoff characteristics, and determining how subbasins are combined and routed downstream. The remainder of the HEC-HMS model input is divided into a series of operations. Each operation computes land surface runoff from a subbasin, combines two or more hydrographs, or performs flood routing through a channel reach or reservoir. Each operation produces a flow hydrograph as its output. Hydrographs can be added together (combined) to represent the confluence of two streams. The model graphical user interface and example of results are shown in Figure 5-1 below.

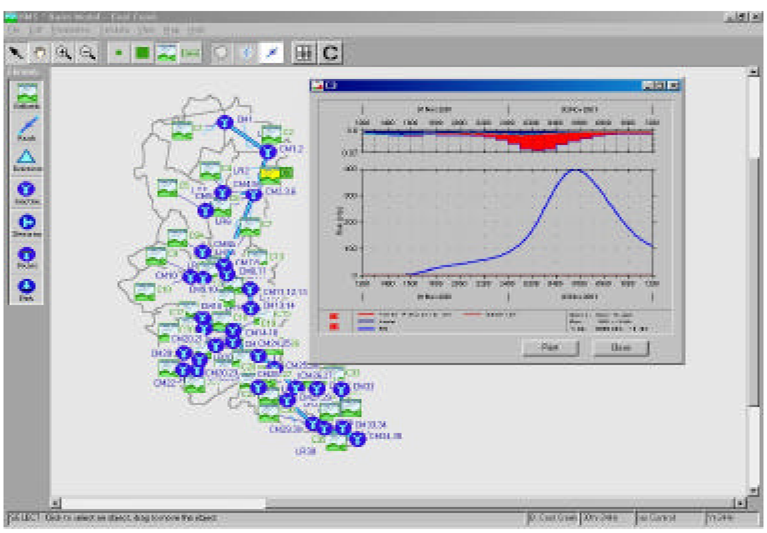


Figure 5-1 – HEC-HMS Model Graphical Interface

The following sections describe the design rainfall data, subbasin parameters, routing of subbasin flows, and model calibration for the watershed. A copy of the HEC-HMS summary output for the 2-, 10, 25-, 50-, and 100-year rainfall events (24-hour duration storm) is provided in Appendix E.

5.2.1 Design Rainfall

The watershed analyses focused on system performance for synthetic (predetermined) rainfall events. A design storm event is defined by precipitation depth, duration, and time distribution. Precipitation depths for various storm durations were obtained from "Bulletin 71 - Rainfall Frequency Atlas of the Midwest" (Midwestern Climate Center and Illinois State Water Survey, 1992). Time distributions (called Huff curves) were used as published in the above referenced Bulletin 71. These "Huff curves" distribute rainfall over the duration of the storm. Different curves (referred to as quartiles) are used for different duration storms. Storms less than 6 hours in duration use the first quartile distribution. Storms with durations of 6 to 12 hours use the second quartile distribution. Storms with durations greater than 12 hours but less than or equal to 24 hours use the third quartile distribution. A fourth quartile distribution is also available for storm durations greater than 24 hours; however, storms longer than 24 hours are not typically used in urban stormwater management analyses. Tables 5-1 and 5-2 list design rainfall depths and distributions.

5.2.2 Subbasin Parameters

The Cool Creek watershed was subdivided into 36 individual subbasins using critical analysis points as subbasin break points. Subbasin delineation was performed using the 2-foot contours in the Hamilton County GIS.

Stormwater runoff from each subbasin was computed using the Soil Conservation Service (SCS) curve number method available in HEC-HMS. Required parameters include subbasin area, curve number, and basin lag time. The time of concentration for each subbasin was estimated using the SCS TR-55 method. Calculations were based on distance, surface characteristics, slope, and velocity of flow from the most remote point in the subbasin to the subbasin outlet. The time of concentration, measured in hours, was converted to the subbasin lag time using the HEC-HMS recommended factor of 0.6.

Subbasin curve numbers were determined using a weighted average of curve numbers assigned to individual sub-areas of homogeneous land use and soil types. Existing conditions land use data was obtained from GIS maps and aerial photos. Future land use data was determined for undeveloped areas from zoning maps. Soil types were obtained from the SCS soil survey discussed in Chapter 2. The individual curve numbers for each land use and soil were selected from tables in SCS Technical Release 55, Urban Hydrology for Small Watersheds, 1986. Subbasin parameters are summarized in Table 5-3. Subbasins locations are shown on Figure 5-2.

5.2.3 Routings

A key feature of the HEC-HMS model is its capability to route stormwater runoff hydrographs through various drainage system components such as detention basins, culverts, and channel reaches. Appropriate flow routings enhance the accuracy of the representation of the watershed response to storm events by incorporating the attenuation of peak flows and time delay of hydrographs which occur as a flood wave travels through the storm system. Both detention pond storage and channel routings were utilized in the Cool Creek watershed HEC-HMS model.

Table 5-1
Design Rainfall Depths

Storm Duration (hours)	Rainfall Depth by Recurrence Interval (inches)					
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
1	1.37	1.71	2.00	2.43	2.80	3.21
3	1.87	2.33	2.72	3.30	3.81	4.28
6	2.19	2.73	3.19	3.87	4.46	5.13
12	2.54	3.17	3.70	4.49	5.18	5.95
24	2.92	3.64	4.25	5.16	5.95	6.84

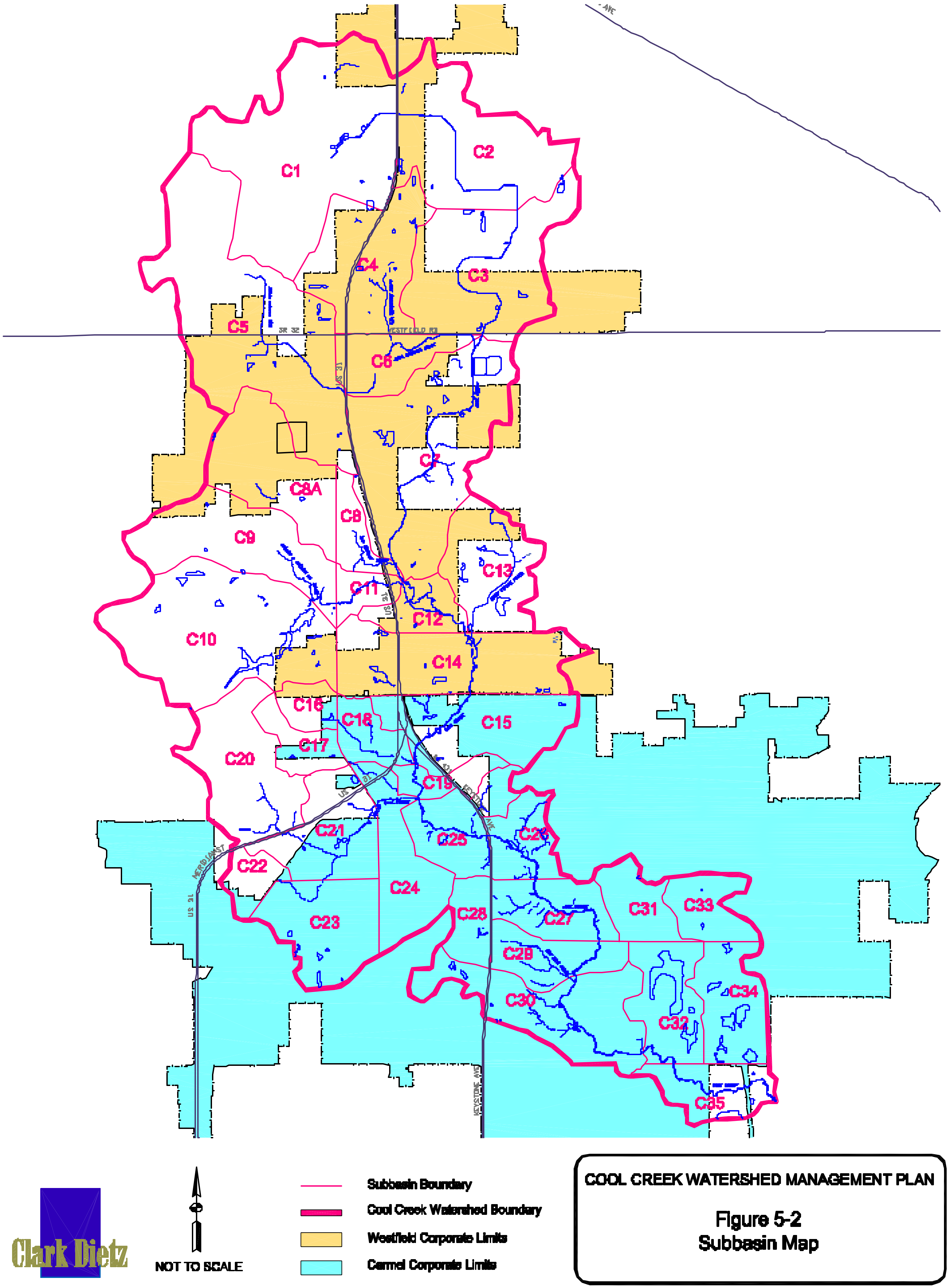
Table 5-2
Design Rainfall Time Distributions

Cumulative Storm Time (%)	Cumulative Storm Rain (%)			
	First Quartile*	Second Quartile	Third Quartile**	Fourth Quartile
5	12	3	2	2
10	25	6	5	4
15	38	10	8	7
20	51	14	12	9
25	62	21	14	11
30	69	30	17	13
35	74	40	20	15
40	78	52	23	18
45	81	63	27	21
50	84	72	33	24
55	86	78	42	27
60	88	93	55	30
65	90	87	69	34
70	92	90	79	40
75	94	92	86	47
80	95	94	91	57
85	96	96	94	74
90	97	97	96	88
95	98	98	98	95
100	100	100	100	100

* First quartile was used in flow computations for smaller tributaries.
** Third quartile was used to compute flows in Cool Creek.

Table 5-3
Subbasin Hydrologic Parameters

Subbasin	Area (sq. mi.)	Time of Concentration (hrs)	Lag Time (hrs)	Curve Number
C1	1.88	3.33	2.00	81
C2	1.18	4.94	2.96	81
C3	1.14	4.04	2.42	80
C4	0.89	2.88	1.73	80
C5	1.95	4.47	2.68	75
C6	0.40	3.07	1.84	77
C7	1.62	4.55	2.73	79
C8	0.18	1.28	0.77	70
C8A	0.67	2.76	1.66	81
C9	0.86	3.12	1.87	81
C10	1.48	2.14	1.28	78
C11	0.17	1.42	0.85	73
C12	0.26	2.39	1.43	66
C13	0.63	2.18	1.31	78
C14	0.87	1.49	0.89	84
C15	0.77	2.58	1.55	73
C16	0.19	1.11	0.67	82
C17	0.24	1.70	1.02	82
C18	0.21	1.36	0.82	79
C19	0.15	1.19	0.71	81
C20	0.78	2.56	1.54	81
C21	0.58	2.08	1.25	82
C22	0.19	0.98	0.59	81
C23	0.65	3.06	1.84	83
C24	0.52	1.90	1.14	74
C25	0.48	2.31	1.39	80
C26	0.35	1.05	0.63	71
C27	0.43	2.72	1.63	75
C28	0.24	1.06	0.64	82
C29	0.36	1.12	0.67	72
C30	0.97	2.00	1.20	75
C31	0.30	1.75	1.05	75
C32	0.53	1.76	1.06	78
C33	0.30	1.09	0.66	73
C34	0.46	2.41	1.45	80
C35	0.50	2.14	1.28	74



COOL CREEK WATERSHED MANAGEMENT PLAN

Figure 5-2
Subbasin Map

5.3 XP-SWMM MODEL DEVELOPMENT

XP-SWMM2000 (Version 8.5), produced by XP Software Inc. is used for free surface open channel and closed conduit flow modeling and for modeling pressure flow networks. The model is based on the EPA Stormwater Management Model (SWMM), which has been in continuous use since approximately 1970. XP-SWMM offers a graphical user interface and detailed model output.

XP-SWMM2000 was used on the Cool Creek watershed project to simulate and evaluate the impact of off-line detention facilities. Off-line facilities were analyzed because on-line basins can create more negative environmental impacts and require a dam safety permit (for drainage areas greater than one square mile). Dam safety issues significantly increase the cost of design, construction, and maintenance of a detention facility. Off-line facilities are more complex to analyze; hence the XP-SWMM2000 model was utilized.

Off-line facilities require a side-channel diversion weir to divert channel flow into the basin when flows in the natural channel begin to rise during a storm event. A restricted outlet is created at the downstream end of the off-line basin to temporarily store flow and reduce downstream flow rates and velocities. XP-SWMM is capable of analyzing the unsteady flow components associated with the interface between the channel, diversion weir, storage facility, and outlet pipe. Figure 5-3 illustrates the XP-SWMM interface for the off-line storage facility modeling.

In this XP-SWMM analysis, an upstream hydrograph is generated using the same hydrologic methodology utilized by the HEC-HMS model. The hydrograph is routed through links that represent the natural stream channel of Cool Creek. A side channel weir is represented along the channel. Flow is diverted into the off-line detention basin storage node. The outflow from the detention basin is restricted, in this case by an orifice controlled structure. Flow is conveyed back to the natural stream channel via a conduit. This hydraulic system is controlled by differentials in water surface elevations between the pond and the channel. Flow will divert into the off-line basin until it is full, in which case flow would bypass the facility and continue downstream via the natural channel. Outflow from the off-line basin will flow back to the natural stream as the hydraulic gradeline in the natural channel subsides.

The location, size, effectiveness, and cost of recommended regional off-line detention storage facilities are summarized in Chapter 7.

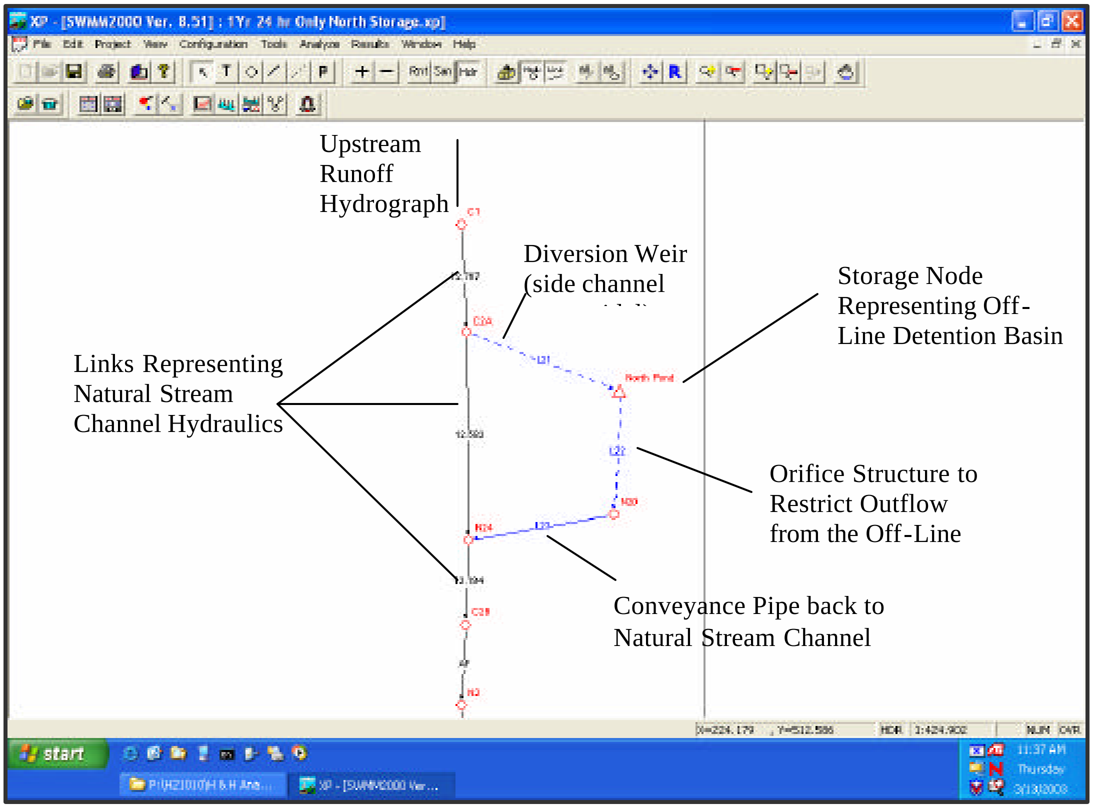


Figure 5-3
XP-SWMM Representation of Off-Line Detention Basin

5.4 MODEL CALIBRATION/VERIFICATION

Hydrologic model calibration/verification was performed by comparison to other analyses or methods and comparing predicted results to general field observations. Detailed comparison of computed hydrographs to gauged stream flow data was not possible because there are no stream gauging stations (and associated rain gauging network) in the Cool Creek watershed. The HEC-HMS model computed flows were compared to those listed in the Flood Insurance Study. The Flood Insurance Study flows were based partly on previous HEC-1 modeling of Cool Creek watershed by IDNR (note: HEC-1 is the predecessor of HEC-HMS). Table 5-4 summarizes the comparison of HEC-HMS model results to previous analyses by IDNR and to the Flood Insurance Studies.

The comparison shows the HEC-HMS model results to be comparable to the IDNR and FIS results, though somewhat lower for the 10-year and higher for the 100-year events. The HEC-HMS model has a more detailed representation of the watershed (36 subbasins) as compared to the IDNR HEC-1 model (10 subbasins). Also, the HEC-HMS model considered an existing regional detention facility on a tributary of the Osborn & Collins # 2 Drain. The IDNR model did not consider this facility as it is privately owned. IDNR will only consider existing storage facilities if they are owned, operated, and maintained by a public entity.

Table 5-4
HEC-HMS Model Results Comparison to IDNR and FIS Results

Location Along Cool Creek	10-Year Storm (cfs)			100-Year Storm (cfs)		
	HEC-HMS	IDNR HEC-1	FIS	HEC-HMS	IDNR HEC-1	FIS
At Mouth at White River	2690	3508	3000	5078	5409	6000
At 116th Street	2601	3394	2700	4892	5223	5400
At Little Cool Creek Confluence	2310	2883	2220	4597	4336	4300
At 146th Street	1842	N/A	2425	3977	N/A	3720
At Osborn & Collins # 2 Confluence	1692	2116	N/A	3732	3244	N/A
At Anna Kendall Confluence/SR 32	1152	1493	1280	2448	2394	2420

The HEC-HMS model also computes flows consistent with observed field conditions for smaller storm events. The HEC-HMS model predicts that Cool Creek would be out of its normal channel banks along its lower reaches in Carmel for the 1-year storm (about 2.5 inches over 24 hours). This modeled condition is consistent with observations to 2-inch and greater storm events that occurred over the course of the project when Cool Creek was observed to be out of its channel banks.

Overall, the HEC-HMS model produces reasonable results consistent with IDNR analyses and with observed field conditions. Additional calibration would require installation of either permanent or temporary stream gauging stations. The County is considering entering into an agreement with the USGS to install and maintain a permanent gauging station on Cool Creek and sharing the cost with Carmel and Westfield. USGS has indicated a new station would cost $5,000 for initial installation and $10,200 annually for maintenance of the station.

5.5 EVALUATION RESULTS

The HEC-HMS flow results were used as inputs to the hydraulic analysis and to develop solutions to flooding problems (Chapters 6 and 7). The model was also used to evaluate the effectiveness of current stormwater detention requirements and existing regional storage facilities in the watershed.

5.5.1 Current Stormwater Detention Requirements

The hydrologic model was used to simulate the cumulative effects of future development in the watershed and evaluate the appropriateness of current stormwater management requirements. Current detention standards require control of 100-year and 10-year storms. For a given site, the 100-year post-development peak rate of runoff must be restricted to the 10-year pre-development peak rate. The 10-year post-development flow must be restricted to the 2-year pre-development peak rate.

The effectiveness of this policy was evaluated by using future land use runoff curve numbers in undeveloped or partially developed subbasins. Storage routing routines were input at the downstream end of these subbasins to represent current detention requirements (control of the 100-year and 10-year post-development flows to 10-year and 2-year pre-development rates, respectively).

The results of this analysis are illustrated in Figure 5-4 which compares existing conditions (blue) and "full build-out" conditions with current detention standards (magenta). The flow vs. time graphs (hydrographs) represent the 100-year and the 1-year storms (24-hour duration) and are located at 146th Street.

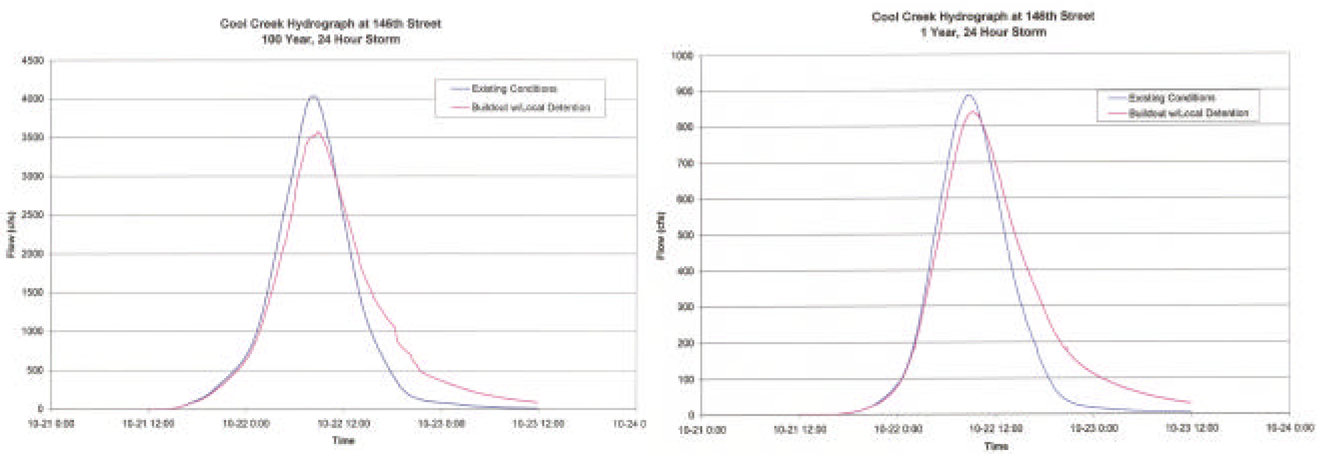


Figure 5-4
Hydrologic Impact of Future Development

The hydrologic analysis shows that current detention standards will be effective in controlling peak flow rates and corresponding flood elevations. However, these hydrographs also illustrate the impact of urbanization on the *volume* and *duration* of stormwater runoff. Under developed conditions, peak flow is reduced but it takes longer for flows to recede.

Urbanization can alter the geometry and stability of stream channels. Larger and more frequent discharges that accompany watershed development cause downstream channels to enlarge, by widening, downcutting, or a combination of both. This is occurring in the lower reaches of Cool Creek. Recommended changes to the current detention standards to help address water quality and channel erosion are included in Section 7.8 of Chapter 7.

5.5.2 Existing Regional Detention Facilities

Two existing regional detention facilities were evaluated as part of the hydrologic analysis. The first is the Village Farms Subdivision lake and dam and the second is storage area created by an undersized culvert at an abandoned railroad embankment on the Anna Kendall Drain.

Village Farms Lake and Dam

The Village Farms Subdivision lake and dam is an engineered on-line stormwater detention facility. The dam was constructed in 1979 – 1980 as a Class 'B' structure. The tributary drainage area is approximately one square mile. The surface area of the lake was increased from 12.7 acres to 16.14 acres in 1996. A hydraulic report was prepared by Weihe Engineers, Inc. in July 1996 to evaluate the hydraulics of the lake enlargement. The hydrologic/hydraulic analysis was completed for large storms only (100-year through the Probably Maximum Precipitation event). The report presents the following results (a 6-hour duration storm was used in the analysis):

Frequency	Inflow (cfs)	Outflow (cfs)	Stage
100-year	1000.7	87.1	877.56
200-year	1394.5	218.0	878.98
300-year	1521.9	300.3	879.18
400-year	1633.3	376.5	879.34
500-year	1712.8	437.3	879.46
½ PMP*	3472.0	2471.5	881.92
PMP*	7112.0	---	Overtop Dam

** PMP: Probable Maximum Precipitation*

The 1996 analysis appears to overestimate the effectiveness of this lake in controlling flood flows in that it accounts for storage that is actually not available. The normal permanent pool elevation for the lake is 873.80 feet. The stage-storage-discharge relationship shown in the 1996 report identifies storage below the normal pool, starting at an elevation of 862 feet and providing approximately 95 acre-feet at the normal pool elevation of 873.80 feet. Unless the lake was completely drained down to elevation 862.0 feet (presumably the bottom of the excavated pond) before a storm event this storage would not be available to attenuate peak inflows. The runoff curve number of 92 used in the 1996 report was much higher than the curve number of 78 computed in this project. A curve number of 92 is appropriate for a highly impervious urbanized commercial/ business district. The zoning map for Westfield – Washington Township shows this area as being zoned single family residential, low density, which is more consistent with a CN of 78. Also the time of concentration in the 1996 analysis was much shorter than in the current HEC-HMS analysis.

Using a curve number of 78, a longer time of concentration, and only accounting for storage above the permanent pool, the HEC-HMS model predicts the following flow reductions for the 2-, 10- and 100-year storm events:

Storm Event (6-hr duration)	Peak Inflow (cfs)	Peak Outflow (cfs)	Percent Reduction	Storage (ac-ft)
2-year	151	55	64%	25
10-year	291	81	72%	49
100-year	610	256	58%	97

The HEC-HMS analysis shows that the Village Farm lake and dam provides significant flood control benefits.

Anna Kendall Drain

A 48-inch culvert under an abandoned railroad embankment creates a significant impoundment area upstream (south) of Park Street on the Anna Kendall Drain. The drainage area at this point is approximately 2 square miles. Although there is significant volume in the impoundment area (approximately 80 acre-ft), an existing breach in the embankment limits the amount of flow that can be stored. Improvements at this location are needed to restore and maintain the flood control benefits of this storage area. The effectiveness of the storage area and specific improvements needed are presented in Section 7.7.3 of Chapter 7.

5.6 SUMMARY AND CONCLUSIONS

A hydrologic analysis of the Cool Creek watershed was completed using the hydrologic computer model HEC-HMS. A second model, XP-SWMM2000, was used to supplement the HEC-HMS model in analyzing proposed off-line regional detention basins. The following conclusions were formed as a result of the hydrologic analysis.

- Existing stormwater detention standards will effectively control peak flows and localized flooding as the watershed continues to develop, especially for larger storm events. However, the volume and duration of flow will increase, especially for the smaller more frequent storm events. This may lead to additional streambank erosion. Modifying detention pond design requirements to provide an extended detention time for the 1-year or "first flush" storm will help reduce erosion and improve water quality.

- Two existing regional detention facilities in the watershed provide significant flood control benefits, though the Anna Kendall storage area is currently ineffective due to a breach in the embankment.

- Additional regional detention facilities in the upper reaches of Cool Creek (discussed in detail in Chapter 7) will provide additional flood control benefits and help reduce downstream channel erosion.